Working Group on the Strategy for the Realization of the International Height Reference System (IHRS)

Splinter meeting at GGHS2016
Wednesday, Sept. 21, 2016
Laura Sánchez

-Brainstorming and definition of action items-

In blue: additions after the discussions carried out during the splinter meeting.

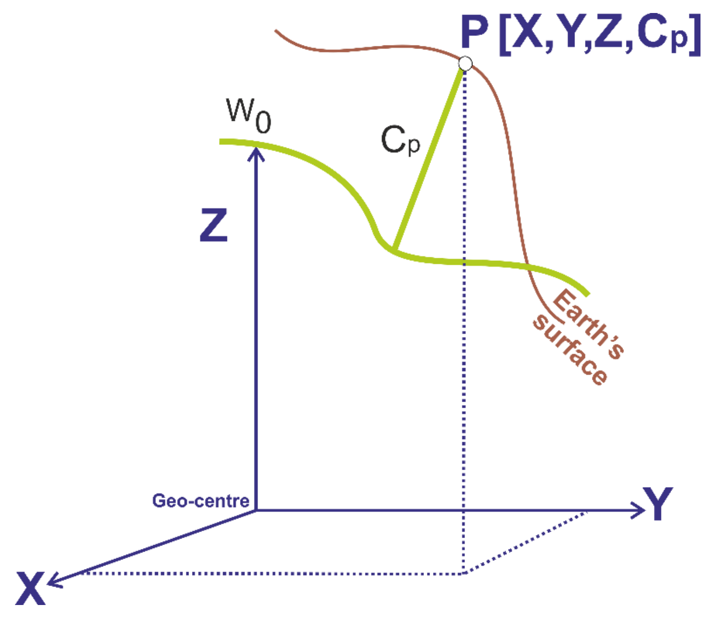
Working Group on the Strategy for the Realization of the International Height Reference System (IHRS)

- Term 2015 – 2019
- Reports to GGOS Focus Area 1
- Contributors
  - GGOS Focus Area 1
  - International Gravity Field Service (IGFS)
  - IAG Inter-commission Committee on Theory (ICCT)
  - IAG Commission 2 (Gravity field)
  - IAG Commission 1 (Reference Frames)
  - Regional sub-commissions (geometry and geoid modelling)
- Interaction with
  - GGOS Bureau of Products and Standards
  - GGOS Bureau of Networks and Observations
  - IAG Joint Working Group Establishment of the GGRF
- Contact: lm.sanchez@tum.de, http://ihrs.dgfi.tum.de
- Initial members: L. Sánchez (chair, Germany), J. Ågren (Sweden), M. Amos (New Zealand), R. Barzaghi (Italy), S. De Freitas (Brazil), W. Featherstone (Australia), T. Gruber (Germany), J. Huang (Canada), J. Ihde (Germany), G. Liebsch (Germany), J. Mäkinnen (Finland), U. Marti (Switzerland), P. Novak (Czech Republic), M. Poutanen (Finland), D. Roman (USA), D. Smith (USA), M. Véronneau (Canada), Y. Wang (USA), M. Blossfeld (Germany), J. Böhm (Austria), X. Collilieux (France), M. Filmer (Australia), B. Heck (Germany), R. Pail (Germany), M. Sideris (Canada), G. Vergos (Greece), C. Tocho (Argentina), D. Avalos (Mexico).

International Height Reference System (IHRS) IAG Resolution No. 1, Prague, July 2015

1) Geopotential reference system co-rotating with the Earth.

2) Coordinates of points attached to the solid surface of the Earth are given by
   - geopotential values $W(\mathbf{X})$ (and their changes with time $\dot{W}$), and
   - geocentric Cartesian coordinates $\mathbf{X}$ (and their changes with time $\dot{\mathbf{X}}$) in the ITRS.



3) Potential values $W(\mathbf{X})$ are to be transformed into potential differences with respect to a conventional W_0 value:

$$-\Delta W = C_P = W_0 - W_P\,;\ C_p(t_0,\mathbf{X});\ dC_p(\mathbf{X})/dt$$

4) Parameters, observations and data in mean-tide system/mean crust (to support the combination of oceanic and continental realizations).

What is going on?

1) Position paper with the definition of the IHRS as support for the IAG 2015 Resolution 1; Johannes Ihde (initiator), Riccardo Barzaghi, Christoph Foerste, Thomas Gruber, Gunter Liebsch, Urs Marti, Roland Pail, Hermann Drewes, Michael Sideris, Laura Sánchez. Expected to be ready by end of September 2016, to be submitted to J Geod.
2) Paper with the *conventions* for the *conventional* W_0 value included the IAG 2015 Resolution 1; L. Sánchez, R. Cunderlík, N. Dayoub, K. Mikula, Z. Minarechová, Z. Šíma, V. Vatrt, M. Vojtíšková. J Geod (2016) 90:815–835, DOI 10.1007/s00190-016-0913-x.
3) Strategies for the vertical datum unification; M. Sideris and L. Sánchez.

Realization of the IHRS: International Height Reference Frame (IHRF)

Primary needs:

1) Establishment of a vertical reference network as the main component of the IHRF.
2) Determination of potential values W_P (and their changes $\dot{W}_P$) at the reference network stations as accurate as possible.

- Inferred (expected) accuracy for W_P according to the GGOS requirements:
  - Positions: ~ 3×10^{-2} m^2s^{-2} (about 3 mm).
  - Velocities: ~ 3×10^{-3} m^2s^{-2} (about 0.3 mm/a).
- Let's start with:
  - Positions: 10×10^{-2} m^2s^{-2} (about 1 cm).
  - Velocities: 10×10^{-3} m^2s^{-2} (about 1 mm/a).
- Depending on the accuracy of the potential values W_P, different orders for the reference stations can be introduced; e.g. a core network, a first-order network, densification networks, etc.

Proposal for the Reference network

1) Hierarchy:
   - A global network → worldwide distribution, including
   - A core network → to ensure perdurability and long term stability
   - Regional and national densifications → local accessibility

2) Collocated with:
   - fundamental geodetic observatories → connection between position vectors $\mathbf{X}$, gravity potential W, time laboratories (atomic and optical) clocks, and gravity laboratories (absolute gravity $\mathbf{g}$ and its changes) → to support the GGRF;
   - continuously operating reference stations → to detect deformations of the reference frame; **what about gravity changes? Can they be monitored with satellite techniques only? Or repeated terrestrial gravity surveys are necessary?**
   - geometrical reference stations of different densification levels → to allow access to the IHRF also in remote areas (potential values at these stations are also needed!);
   - reference tide gauges and national vertical networks → vertical datum unification;
   - reference stations of the new Global Absolute Gravity Reference System (see IAG Resolution 2, Prague 2015).

The IHRF is understood to be a component of the Global Geodetic Reference Frame (UN GGRF resolution 2015).

Possibilities for the determination of W_P

1) Combined (high-resolution) gravity field models: $W_P = f\left(X_P, GGM\right)$

   - At present, it is not suitable. For instance, differences between EGM2008 and EIGEN6C4 (n=2190) up to ±1300 x 10^{-2} m^2s^{-2}
   - **A good possibility may be a new generation of GGM, but it may take five years or longer.**

2) Levelling + Gravimetry: $W_P = \left(W_0^{local} + \delta W\right) - C_P;\ C_P = \int_0^P g\, dn$

   - Problem: geopotential numbers C_P refer to local reference levels W_0^{local}.
   - Requirement: the values W_0^{local} must be known; i.e. the vertical datum unification w.r.t. the IHRS is required.
   - The vertical datum parameters δW can presently be estimate with an accuracy from some cm (5 cm) to 1 m (50 x 10^{-2} m^2s^{-2} to 1000 x 10^{-2} m^2s^{-2}).
   - This strategy may be useful for the IHRF densification, but not for establishing the core network of the IHRF.

Possibilities for the determination of W_P

3) High-resolution gravity field modelling:

$$W_P = W_{P,satellite-only} + W_{P,high-resolution}$$

Satellite-only gravity field modelling:

Satellite orbits and gradiometry analysis

Satellite tracking from ground stations (SLR)

Satellite-to-satellite tracking (CHAMP, GRACE)

Satellite gravity gradiometry (GOCE)

Satellite altimetry (oceans only)

+

High-resolution gravity field modelling:

Stokes or Molodensky approach

Satellite altimetry (oceans only)

Gravimetry, astro-geodetic methods, levelling, etc.

Terrain effects

$$W_P = U_P + T_P$$

$$T_P = T_{P,satellite-only} + T_{P,residual} + T_{P,terrain}$$

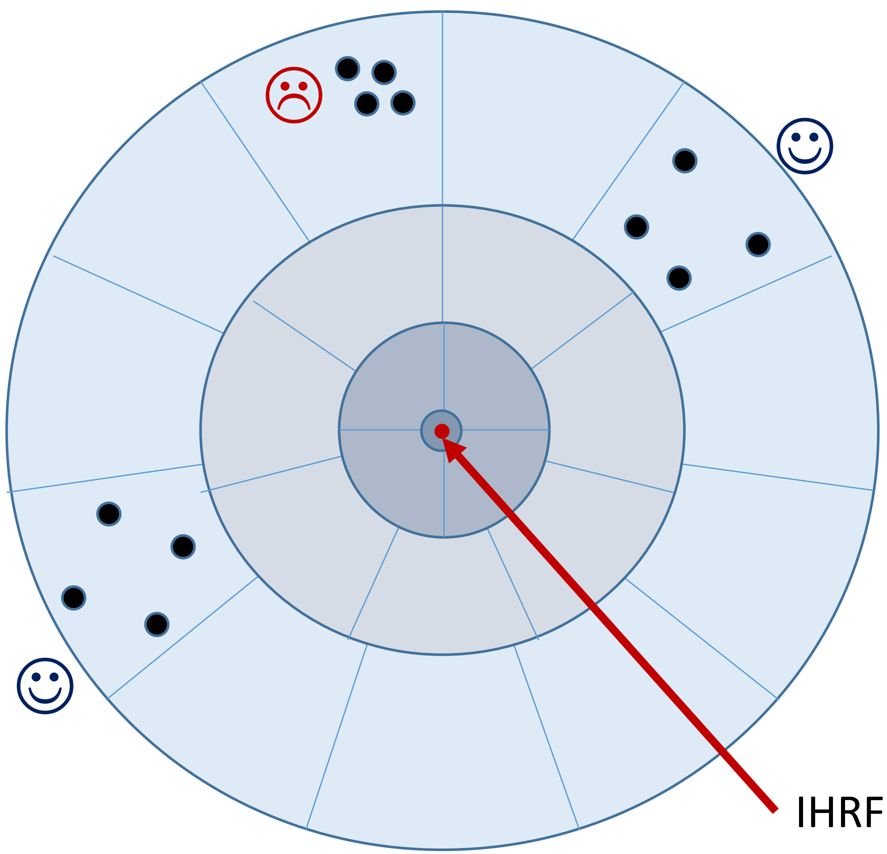
One GGM

Terrestrial gravity data

One DTM

Minimum requirements on the terrestrial gravity data

- Gravity points with ±20 μGal accuracy needed to estimate the **residual** (quasi-)geoid height with ±5 mm uncertainty.
- Uncertainties of GGM and DTM must be added.



IHRF station

Template according to the gravity effect on the geoid ($\Delta g = 1 \cdot 10^{-6}\ ms^{-2} \rightarrow 1\ mm$)

Distance	Compartments	# of points	**Rounded values**
10 km	1	4	**5**
50 km	4	16	**15**
110 km	7	28	**30**
210 km	11	44	**45**
Sum	23	92	**95**

See comments at the splinter meeting in the next slide.

Minimum requirements on the terrestrial gravity data

Comments at the splinter meeting:

- The point distribution is very optimistic. In mountain regions more gravity points are needed.
- In some regions are more gravity field-related data available: not only gravity observations, but geopotential numbers, deflexion of the vertical observations, grids of mean gravity anomaly values, etc. If these data are available, they should be included in the computations.
- Agreement: The point distribution data presented in the previous slide is declared as “the minimum requirement” and it should be satisfied as far as possible, specially in those regions where no data are available.

How to get the terrestrial data?

Core network	🙂	Plan A: To ask the GGOS Bureau for Networks and Observations to collect the data (data may exist or have to be observed).
	🙂	Plan B: To ask BGI and/or the responsible for each station directly (with the help of the regional sub-commissions).
First-order densification networks	😐	Plan C: To ask national/regional agencies responsible for the geoid modelling to compute the residual component of the disturbing potential T_{res} directly. To ensure consistency, we have to define how they have to compute it.
Second-order densification networks	😐	Plan D: To use existing grids with mean observed gravity anomalies (not from GGMs); e.g. from BGI or NGA.
If no other way	☹	Plan E: To take an existing local geoid model.
	☹	Plan F: To use a high-degree GGM.

Comments at the splinter meeting: Plans A and B are very ambitious and may not be realizable.
Agreement: we try to realize Plans A and/or B. If we fail, we can follow any of the other four plans.
At the end, if no one of these plans is successful, we have always the possibility to use a GGM.

Computation of T_{res} (core network, first order network)

1) The same GGM for the long wavelength components? Which one? Should we outline the minimum characteristics of the GGM we need? Who should do this?
2) The same DTM for the short wavelength components? Which one?
3) If the Stokes approach is used, do we need to apply the same orthometric reductions for the gravity values? Or is it better to use Molodensky or a fixed GVBP directly?
   - A fixed GBVP is independent of local height systems
   - Molodensky has to be iterative.
4) Should kernel functions be prescribed?
5) Are ellipsoidal corrections to be considered?
6) Computations in tide-free or zero-tide system?

Jonas Ågren - IAG SC 2.2: Methodology for Geoid and Physical Height Systems
Jianliang Huang: ICCT JSG 0.15: Regional geoid/quasi-geoid modelling – Theoretical framework for the sub-centimetre accuracy

See comments at the splinter meeting in the next slide.

Computation of T_{res} (core network, first order network): comments at the splinter meeting

- Some colleagues say that the use of terrestrial data to refine the signal contained in the GGM allows to apply any GGM. A convention about a GGM is not necessary.
- Other colleagues say that using different GGMs produces different potential values and therefore, a conventional GGM is really needed.
- There is no agreement in this point.
- To advance, we will start outlining the metadata necessary to explain the computation of the GGMs, e.g., numerical standards, tide systems, physical models, procedures, commission and omission errors, accuracy, etc. This is called "characteristics of the GGM".
- For the gravity field modelling, the W_0 value should be presented together with the values for GM and omega (Earth's rotation velocity). Agreement: this is part of the standards to be compiled within the activities of the WG in cooperation with the GGOS-BPS.

Computation of T_{res} (core network, first order network): comments at the splinter meeting

- A clear guidance in the determination of the residual component of $\boldsymbol{T}$ will be useful:
  1) To determine the *absolute* potential values $\boldsymbol{W_P}$
  2) To realize the global reference level $\boldsymbol{W_0}$ at regional and local scales
  3) To improve the vertical datum unification (estimation of the vertical datum parameters $\boldsymbol{\delta W}$)
- The determination of the residual component of $\boldsymbol{T}$ is not trivial. Further studies and a lot of cooperation are needed. One possibility is to install an additional working group under the coordination of the SC 2.2.
- The WG on the IHRS realization is open to everyone who wants to join.
- To not duplicate efforts, it is agreed to maintain this activity within the WG on the IHRS realization and contributions related to this topic will be coordinated/compiled by Jonas Ågren and Jianliang Huang.

Handling of tide systems

The IAG resolution states "**Parameters, observations and data in** mean-tide system/mean crust"

1) General transformation formulae for products (gravity values, GGM coefficients, disturbing potential (quasi-geoid or geoid heights), geopotential numbers).

2) Conventional transformation formulae (the same as in (1) with conventional Love numbers, ellipsoid parameters, etc. included).

3) Do we need formulae for pre- and processing? Or is this responsibility of people/services generating the products?

Mäkinen Jaakko

Comments at the splinter meeting: we should take care of the transformation of the height-related products; i.e., a post-processing transformation. The tide system used in the generation of the input data (like ITRF or GGM) is responsibility of the processing centres producing that data. It is desired that they well document the tide system they use and the tide system in which their products are given.

Time variations of W_P

Satellite-only gravity field modelling:
Satellite orbits and gradiometry analysis
Satellite tracking from ground stations (SLR)
Satellite-to-satellite tracking (CHAMP, GRACE)
Satellite gravity gradiometry (GOCE)
Satellite altimetry (oceans only)

+

High-resolution gravity field modelling:
Stokes or Molodensky approach
Satellite altimetry (oceans only)
Gravimetry, astro-geodetic methods, levelling,etc.
Terrain effects

We have to consider (at least):

Solid Earth/ocean/atmospheric tides	Plate tectonic motion
Ocean/atmospheric/hydrological loading	Crustal deformation
Precession, nutation	Post-glacial rebound
LOD, polar motion	Local effects

Are the reduction models sufficiently accurate?
If the position $\mathbf{X}$ of P changes (due to subsidence, uplift, earthquakes, etc.), can we assume $W(\mathbf{X})/dt=W(d\mathbf{X}/dt)$?

Comments at the splinter meeting: this statement is incorrect! The changes in W should be separately analysed. As the changes in $\mathbf{X}$ are derived from continuous or repeated observations, changes in W should be derived from continuous or repeated observations of the gravity field.
New questions: changes of W can be inferred from satellite techniques only, or terrestrial gravity measurements must be also periodically repeated? How many times? How often?

Inspiration

1) The ITRF89 included station positions only (station velocities were neglected).
2) The coordinates were given in zero (mean) tide system.
3) The conversion to ellipsoidal coordinates was using arbitrarily values for a and f (the GRS80 was not considered).
4) Accuracy: from 11 to 60 mm.

It is important to have a “start point”, a “first approximation to the IHRF”. Once it is achieved, it can be improved by considering more and more details, that at the beginning may not be evident.

TABLE OF CONTENTS

IERS Standards

November 1989

Preliminary contents for the IHRS/IHRF standards and conventions

Names in red are understood as coordinators, everyone that wants to join is welcome!

1) Introduction (when the document is ready)
2) Numerical standards (in agreement with the GGOS Bureau for Products and Standards)
3) Definition of the International Height Reference System (based on the paper Ihde et al. 2016 in preparation) Ihde and coauthors
4) Reference level: Conventional W_0 value Sánchez
5) International Height Reference Frame (Pail, Marti, Wziontek, Brazaghi, Sánchez), in agreement with the GGOS Bureau for Networks and Observations
6) Estimation of W_P
   - GGM characteristics for the global component of W_P Gruber
   - Regional component of W_P Ågren, Huang
   - Tide systems (conventions for conversion between them) Mäkinnen
   - Modelling of non-linear motions ???
7) Vertical datum unification Sideris, Sánchez
8) IHRF products and servicing
9) Related resolutions